

MOSFETs and IGBTs differ in drive methods and protection needs

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POWER MOSFETs AND IGBTs BOTH PROVIDE LOW-LOSS SWITCHING, BUT THEY DIFFER MARKEDLY IN DRIVE REQUIREMENTS AND THE NEED FOR PROTECTIVE MEASURES.

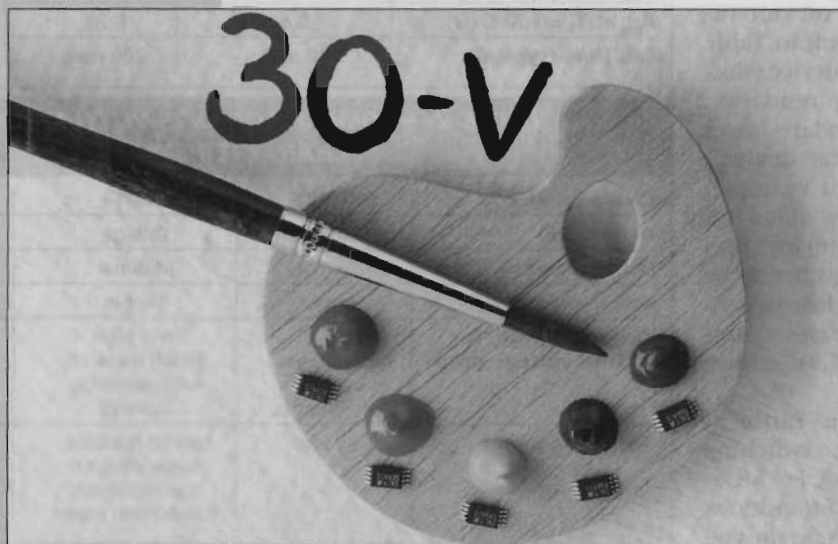
In an ever-increasing number of applications, power MOSFETs and insulated-gate bipolar transistors (IGBTs) are displacing traditional bipolar power transistors. The MOSFETs and IGBTs use less silicon for a given rating and require vastly lower drive power. To choose between the two devices, you must evaluate several criteria and consider how your design will drive and provide protection for the devices.

The processing for MOSFETs and IGBTs is similar, and the devices use identical processing steps, except for substrate polarity. This one-step difference yields the MOSFET and IGBT structures in Figures 1a and 1b. The processing for MOSFETs produces a source-to-drain body diode. In the more complex IGBT structure, an n-

channel MOSFET, an npn transistor, and a junction FET drive the pnp output transistor. (The "collector" and "emitter" labels in Figure 1 are misnomers; those shown are the emitter and collector of the pnp transistor.)

The bipolar npn and pnp in Figure 1b form a silicon-controlled rectifier (SCR) (Reference 1). If the gains of these devices are high enough, the SCR can latch up. The base resistance, R_b , however, prevents the npn from turning on, and the IGBT's equivalent circuit reduces to that in Figure 1c. This structure offers the best of both worlds: the high input impedance of a power MOSFET and the low saturation voltage of a bipolar transistor.

Table 1, derived from Reference 2, provides a quick comparison of the



Power MOSFETs on the Lite Foot family from Siliconix-Temic offer the industry's lowest on-state resistance (28 m Ω) for devices in the eight-pin TSSOP.

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switching performance of MOSFETs and IGBTs. For comparison purposes, the table includes bipolar devices and translates the usual $V_{CE(SAT)}$ for IGBTs to R_{ON} . Two facts spring from this data: First, the bipolar devices are considerably slower than MOSFETs, principally because of the bipolar devices' long turn-off times. Second, the on-state resistance of the bipolars is relatively invariant with temperature, in comparison with the high-temperature coefficients inherent in MOSFETs. This temperature-coefficient information is an important consideration in designing thermal-safety margins into high-power systems.

Table 2 (Reference 3) presents a more general comparison of device characteristics. Thanks to their gate-input structure, MOSFETs and IGBTs are voltage-driven devices, which demand minimal drive power. A bipolar transistor is a current-driven device (output current divided by h_{FE}), so it demands hefty drive power. The input capacitance for MOSFETs and IGBTs, depending on rating, can be considerable, and the drive circuitry must be able to rapidly charge and discharge this high capacitance.

IGBTs win hands down on current-density ratings. The trade-off in Table 2 reflects a compromise in device selection. To maintain latch-up resistance, IGBT manufacturers mandate lower current densities for faster devices. International Rectifier, for example, offers three IGBT families: Standard, Fast, and UltraFast. The company specs these families' current densities to be inversely proportional to their switching speeds. $V_{CE(SAT)}$ increases correspondingly: 1.3, 1.5, and 1.9V, respectively.

The last parameter in Table 2, switching losses, reflects the switching speeds of the various devices. For MOSFETs, both turn-on and -off transitions are very fast. For the IGBTs, again you

face a trade-off: switching speed vs current density hence, faster devices suffer higher conduction losses. The switching times of IGBTs, mostly comprising turn-off times, generally limit the use of these device to systems operating at switching rates lower than 100 kHz.

Table 3 (Reference 2) shows the dramatic trade off in conduction losses vs voltage ratings for MOSFETs. For equal current density per unit of silicon area, MOSFETs' on-state resistance increases exponentially with respect to voltage rating. IGBTs, specified in terms of $V_{CE(SAT)}$ rather than on-state resistance, maintain their low conduction

Power MOSFETs (a) and IGBTs (b and c) have very different equivalent circuits, but their physical structure is identical, except for the substrate polarity.

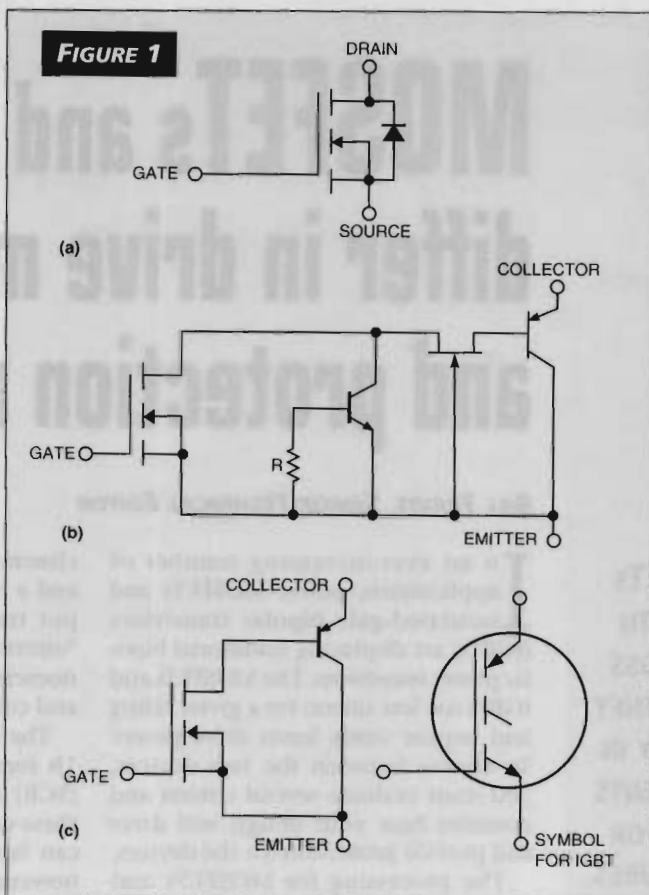


TABLE 1—COMPARISON OF SIMILARLY RATED SWITCHING DEVICES

Characteristic	MOSFET	IGBT	Bipolar
Current rating (A)	20	20	20
Voltage rating (V)	500	600	500
R_{ON} at $T_J = 25^\circ\text{C}$ (Ω)	0.2	0.24	0.18
R_{ON} at $T_J = 150^\circ\text{C}$ (Ω)	0.6	0.23	0.24
Fall time (typical)	40 nsec	200 nsec	200 nsec

TABLE 2—COMPARISON OF SWITCHING-DEVICE CHARACTERISTICS

Characteristic	MOSFET	IGBT	Bipolar
Drive type	Voltage	Voltage	Current
Drive power	Minimal	Minimal	Large
Drive complexity	Simple	Simple	Medium
Current density for a given voltage drop	High at low voltages low at high voltages	Very high (small trade-off with switching speed)	Medium (severe trade-off with switching speed)
Switching losses	Very low	Low to medium, depending on trade-off with conduction losses	Medium to high, depending on trade-off with conduction losses

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losses for all voltage ratings. The MOSFETs in Table 3 have slightly lower voltage ratings than those of the IGBTs; this disparity reflects the MOSFETs' harder avalanche resistance.

Figure 2 from Reference 2 underscores the high current density, thus, the low on-state losses, IGBTs can offer. The graphs show the on-state voltage drops for a MOSFET and two IGBTs of the same die size, with 10A load current. You face a trade-off of IGBT switching speed vs conduction losses. The lowest loss device in Figure 2 is the IRGBC40S from International Rectifier's Standard family of IGBTs; the Ultra-Fast model IRGBC40U offers faster switching and correspondingly higher on-state losses.

In static terms, the input impedance of both MOSFETs and IGBTs is practically infinite. Drive circuitry does not have to supply the significant base cur-

rents that bipolar devices require. For ac operation, however, the impedance is far from infinite. The input capacitance of the devices can range from hundreds or thousands of picofarads to double-digit nanofarads. The driving source for MOSFETs and IGBTs must be able to rapidly charge and discharge this high input capacitance to ensure fast switching of the power device.

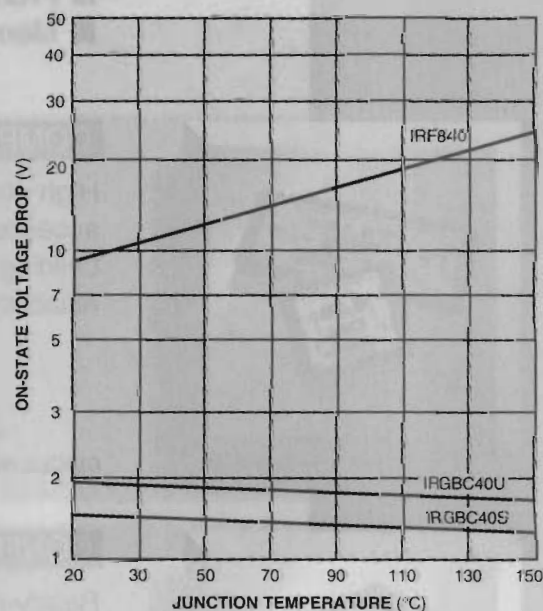
Figure 3, derived from Reference 4, shows three techniques for driving an IRF320 power

MOSFET. In Figure 3a, an open-collector TTL gate drives the device. In this configuration, the MOSFET turns on

**TABLE 3—VOLTAGE DROP VS
DEVICE VOLTAGE RATING**

Rated voltage	IGBT	100	300	600	1200
	MOSFET	100	250	500	1000
Typical voltage drop at 1.7A/mm ² at 100°C	IGBT	1.5	2.1	2.4	3.1
	MOSFET	2.0	11.2	26.7	100

FIGURE 2



For equal die area, IGBTs offer vastly more current density and, hence, lower on-state losses, than do power MOSFETs.

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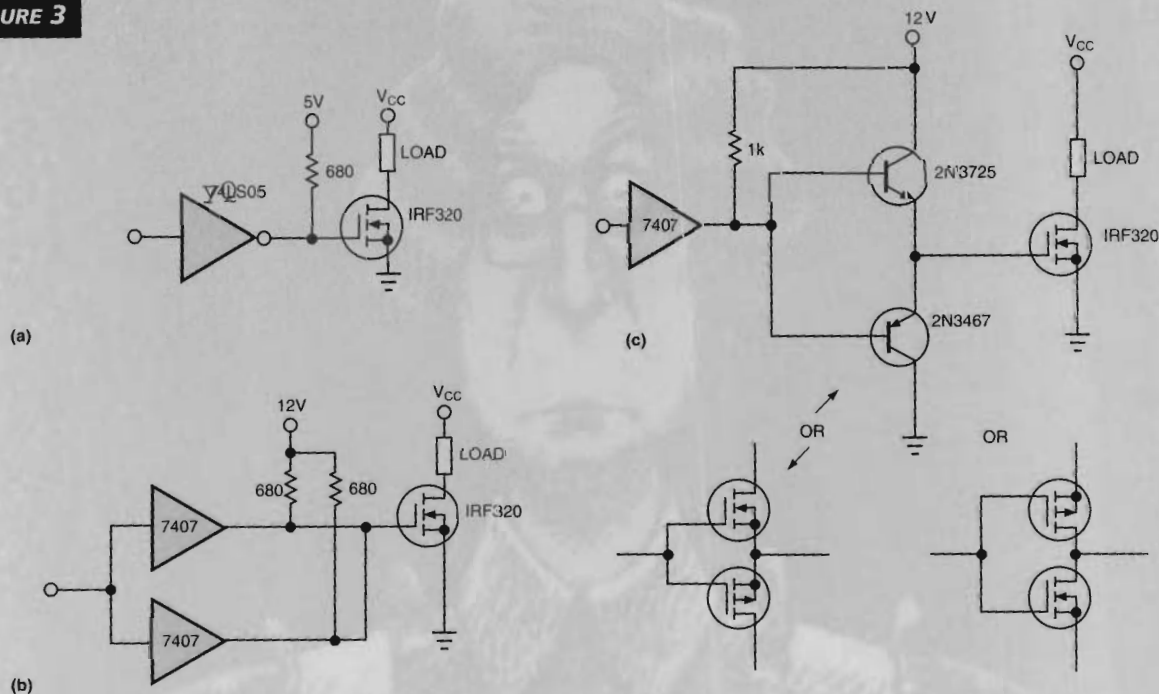
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FIGURE 3



The heftier the drive, the faster a MOSFET switches. The TTL drivers in (a) and (b) provide no sourcing current, so the MOSFET switches on relatively slowly. The active drivers in (c) provide both sourcing and sinking drive, for maximum MOSFET switching speed.

much more slowly (in about 2 μsec) than it turns off. In turn-on mode, the gate-to-source and -drain capacitances charge exponentially through the 680 Ω pullup resistor. In turn-off mode, the saturated output transistor of the TTL gate rapidly discharges these capacitances.

Two parallel high-voltage drivers in Figure 3b provide faster turn-on transitions (about 400 nsec), but this figure is still well below the capability of the MOSFET. To obtain the fastest possible switching (about 40 nsec), the driver circuit must provide active pullup and pulldown drive, as in Figure 3c. You can configure the MOSFET totem poles in either a source-follower or a common-drain connection.

Instead of designing your own driver, you could select from a variety of ICs designed for driving MOSFETs. Table 4 (Reference 5) gives a comparison between the bipolar and common-drain-FET totem poles in Figure 3c and several IC drivers available from Micrel Semiconductor and Unitrode. The

TABLE 4—TOTEM POLES AND IC DRIVERS

Driver	Rise time (nsec)	Fall time (nsec)
FET totem	20	20
UC3710	20	20
MIC4451	20	20
MIC4429	30	30
UC3708	30	30
UC3711	30	40
Bipolar totem	60	70

power MOSFET is an APT5020BN from Advanced Power Technology, switching a 10.5 Ω load connected to a 250V supply. Several of the IC drivers equal the performance of the MOSFET totem pole, and the rest range in performance between the FET and the bipolar totem-pole drivers.

The drive requirements for IGBTs are similar to those for MOSFETs, in that both device types present high values of input capacitance. However, IGBTs

and MOSFETs differ markedly in turn-on threshold voltages. Traditionally, n-channel MOSFETs require 10V gate-source voltage to ensure full enhancement. Now, a wide variety of logic-level MOSFETs is available, with guaranteed on-state resistance at gate-source voltage levels equal to the logic-levels of common digital ICs.

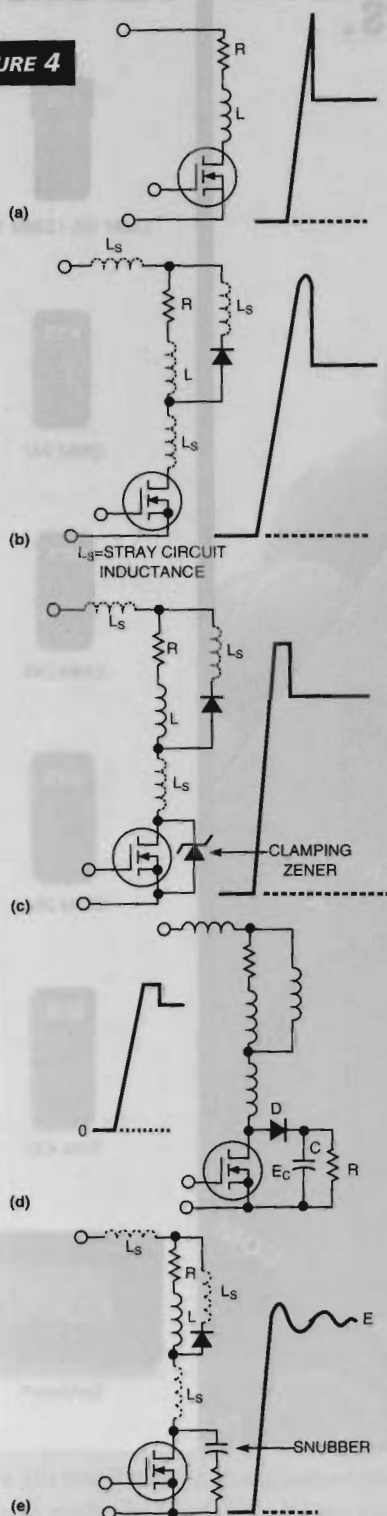
IGBTs require 10V gate-emitter voltage to fully turn on and 0V to fully turn off. Large, high-voltage, and high-current IGBTs and IGBT modules work better with even higher input levels. Powerex, for example, recommends +15V and -10V turn-on and turn-off voltages, respectively, for its large IGBT modules. The company offers a number of hybrid gate drivers to provide those drive voltages to the big modules.

Protective measures

Both IGBTs and power MOSFETs are vastly more robust than bipolar transistors. Their safe operating areas are relatively square, with power limited only by the admissible junction-tem-

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FIGURE 4



The clamping and snubbing circuits in (b) through (e) protect the MOSFET from overvoltage breakdown. The diode-blocked RC network in (d) wastes less power than does the simple snubber in (e).

LOOKING AHEAD

You can expect to see a decline in the number of new power-system designs that incorporate traditional bipolar power transistors. The allure of power MOSFETs and IGBTs in terms of silicon efficiency (read costs), ease of drive, and ruggedness is irresistible. VLSI processing improvements are largely responsible for this technology transformation. The MOSFETs and insulated-gate bipolar transistors (IGBTs) integrate millions of submicron-feature cells in parallel, so these devices' evolution closely follows the progress in digital-IC design.

Semiconductor physicists are working to improve the electrical characteristics of the power devices. The most obvious area for improvement is in reducing on-state resistance (or, for an IGBT, $V_{CE(SAT)}$). Innovations in processing and putting more and more cells in parallel are steadily reducing on-state losses. Another area for improvement is in cutting compromises. Trade-offs, such as those between high speed and on-state losses, high speed and ruggedness (resistance to avalanche and latching), and other traditionally conflicting device traits, are continuously diminishing.

The "wish list" of power-system designers might include the following: p-channel MOSFETs with little or no cost penalty vis-à-vis comparably rated n-channel devices, true p-channel IGBTs, and viable depletion-mode n-channel MOSFETs. Comparably rated n-channel devices and true p-channel IGBTs would allow the design of economical, full-complementary output stages. Depletion-mode n-channel MOSFETs would yield an easy-to-drive high-side switch. Progress on p-channel MOSFETs is already occurring; International Rectifier has reduced the silicon penalty to 2-to-1, vs the 3- or 4-to-1 traditional figure. In the mid-1980s, RCA announced the imminent emergence of a p-channel IGBT with no silicon penalty; apparently, the device never made it out of the laboratory. But we can always hope.

perature rise. In contrast to early devices, modern IGBTs are highly resistant to latch-up when you operate them within data-sheet limits. However, with their thin oxide layers and megacell construction, you must take care to protect both IGBTs and MOSFETs from overvoltage conditions.

Figure 4 (Reference 6) shows various ways to protect power devices from overvoltage conditions arising from inductive effects. Figure 4a shows the result of trying to turn the MOSFET off; the overvoltage transient is an inductive "kick." The diode in Figure 4b clamps the main inductive-kick component, but stray inductances still produce an

overvoltage transient. In Figure 4c, a zener diode or other clamping device clips the transient to a safe level.

Figure 4d shows an alternative clamping arrangement. Capacitor C is a "reservoir" capacitor that charges to a relatively constant voltage, and resistor R dissipates the clamping energy while maintaining the desired voltage across the capacitor. You must carefully select diode D such that its forward-recovery characteristic does not spoil the transient-clamping action of the circuit.

You could also use the simple RC snubber in Figure 4e. However, an RC snubber not only limits the peak voltage, but also lowers the effective switching

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speed. It absorbs energy during the entire switching period, not just at the end of it, as does a voltage clamp. A snubber is, therefore, less efficient than a true voltage-clamping device.

These points are only a few of the aspects involved in choosing and using a power MOSFET or an IGBT. Comprehensive treatments of the drive, protection, and applications aspects of these devices fill entire textbooks. Most MOSFET and IGBT manufacturers publish large amounts of application literature on their products and on power devices in general.

References

1. Mitter, CS, "Application Considerations Using Insulated Gate Bipolar Transistors (IGBTs)," Application Note AN1540, Motorola Inc.
2. Takesuye, Jack, and Scott Deuty, "Introduction to Insulated Gate Bipolar Transistors," Application Note AN1541, Motorola Inc.
3. Clemente, S, A Dubashni, and B Pelly, "IGBT Characteristics," Application Note AN-983A, International Rectifier.
4. Clemente, Steve, "Gate Drive Characteristics and Requirements for Power HEXFETs," Application Note AN-937B, International Rectifier.
5. Dierberger, Kenneth, "Gate Drive Design for Large Die MOSFETs," Application Note APT9302, Advanced Power Technology.
6. Pelly, Brian, "The Do's and Don't's of Using Power HEXFETs," Application Note 936A, International Rectifier.

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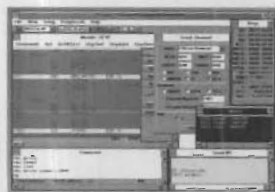
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